7.0 SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

In response to concerns about the declining clarity of Lake Tahoe waters, the Corps of Engineers (CoE), Sacramento District, in cooperation with the CoE Engineer Research and Development Center and the USDA-ARS provided support for a study on sediment loadings and channel erosion in the Lake Tahoe Basin.

7.1 Summary and Conclusions

The study was designed to combine detailed geomorphic and numerical modeling investigations of several representative watersheds with reconnaissance level evaluation of approximately 300 sites to determine which basins and areas were contributing sediment to Lake Tahoe. Numerical modeling of upland- and channel-erosion processes over then next 50 years was conducted using AnnAGNPS and CONCEPTS on three representative watersheds, General and Ward Creeks, and the Upper Truckee River. GIS-based analysis of land use, land cover, soil erodibility, steepness, and geology was used to evaluate upland-erosion across the basin. Channel contributions were determined by comparing cross-sectional geometries of channels originally surveyed in either 1983 or 1992. Sites along General, Logan House, Blackwood, and Edgewood Creeks, and the Upper Truckee River were re-occupied and re-surveyed in 2002. Historical flow and sediment-transport data from more than 30 sites were used to determine bulk suspended-sediment loads (in tonnes) and yields (in tonnes/km^2) for sites all around the lake. Eighteen index stations, defined as those with long periods of flow and sediment-transport data and, located in a downstream position were selected. These stations were used to make comparisons between sediment production and delivery from individual watersheds and between different sides (directional quadrants) of the lake. Fine-grained sediment transport was determined from historical data for 20 sites based on relations derived from particle-size distributions across the range of measured flows.

Suspended-sediment loads and yields vary over orders of magnitude from year to year, from west to east and north to south across the basin. Median annual suspended-sediment loads for index stations range from about 2200 tonnes/yr (T/y) from the Upper Truckee River to 3 T/y from Logan House Creek. Based on the historical data, the largest annual contributors of sediment are in decreasing order, Upper Truckee River (2200 T/y), Blackwood Creek (1930 T/y), Second Creek (1410 T/y), Trout Creek (1190 T/y), Third Creek (880 T/y) and Ward Creek (855 T/y). Data from Second and Third Creeks may be somewhat misleading though because of a short period of data collection in the case of the former, and the fact that data collection occurred during major construction activities in these basins. In fact, analysis of suspended-sediment transport ratings with longer periods of record (17 to 20 years) show that sediment loads from the northeast streams have significantly decreased across the entire range of flows. Based on the historical data, the lowest contributors of suspended sediment from index stations, in increasing order are Logan House (3.0 T/y), Dollar (4.6 T/y), Quail Lake (6.4 T/y), Glenbrook (8.9 T/y), and Edgewood Creeks (21.3 T/y).

That the Upper Truckee River and Trout Creek are major sediment contributors is not surprising given their large drainage areas in relation to the other streams in the Lake Tahoe Basin. Per unit area, the western and northern streams produce the most sediment although for different reasons, and sediment yields from the northern streams have been decreasing since the early 1970's. Suspended-sediment yields from the Upper Truckee River are also decreasing with time but at a slower rate than in Third and Incline Creeks for example. In other parts of the watershed, temporal trends of decreasing loads per unit area and unit water were subtler. No statistically significant trend of increasing suspended-sediment loads or yields was identified as reported recently by other workers.

Fine-grained loads show a similar pattern as total loads with the greatest contributors being the Upper Truckee River (1010 T/y), Blackwood Creek (844 T/y), Trout Creek (462 T/y) and Ward Creek (412 T/y). The lowest contributors are Logan House Creek (2.3 T/y), Dollar Creek (2.6 T/y), Quail Lake Creek (3.2T/y) and Glenbrook Creek (7.0 T/y). In terms of fine-grained loadings per unit area, a slightly different picture emerges. Blackwood, Third, and Ward Creeks, all disturbed streams have the greatest fine-grained suspended-sediment yields at 21.5, 20.2, and 16.4 T/y/km^2. In comparison, the Upper Truckee River produces 7.1 T/y/km^2; General Creek, 2.8 T/y/km^2; and Logan House Creek, 0.4 T/y/km^2.

Sediment yields were also used to discriminate between loadings from disturbed and undisturbed watersheds. For example, although the western streams produce more sediment per unit area than eastern streams General Creek can be considered as a "reference" stream because of a lack of significant human intervention. Sediment yield from General Creek is about 9 T/y/km^2. In contrast, yields from Blackwood and Ward Creeks, streams disturbed to different degrees by human activities are about 66 and 34 t/y/km^2, respectively. On the eastern side of the lake, relatively undisturbed Logan House Creek produces 0.6 t/y/km^2 compared to the developed Edgewood Creek watershed that produces about 3 T/y/km^2. The effects of human disturbance on streams draining the northeast part of the Lake Tahoe watershed (Third, Second and Incline) are shown to have produced orders of magnitude more sediment in the 1970's (during construction and development) than at present.

The contribution of channel materials to sediment loads also varies widely. Undisturbed channels tend to have greater amounts of their sediment load emanating from upland areas. In the General Creek watershed, numerical modeling shows that about 78% of the fine materials passing the downstream-most gauge, originate from upland sources, with only 22% coming from channel sources. Simulations of the percentage of upland sediment contributions may be overestimated because of overestimates of runoff during the low-flow winter months. This results in simulations of erosion preferentially in upland areas rather than in channels because precipitation was simulated as rain instead of snow. Still, similar proportions of upland and channel materials were simulated on Ward Creek, suggesting that this may be typical of the wetter, western watersheds. This is not to say that General and Wards Creeks supply similar amounts of streambank materials. Per unit of channel length, Ward Creek supplies almost 5 times the amount of sediment and fine-grained material from streambanks than General Creek (Table 7-1). Analysis of monumented cross sections shows that on average, 14.6 m^3/y/km of streambank materials (or 1.5 m^3/y/km of fine-grained materials) are eroded from the lower 8.5 km of General Creek. These values are within 27% of those simulated by CONCEPTS. The disturbed channels of Blackwood Creek provide about 217 m^3/y/km of sediment; 12.2 m^3/y/km of fines. This represents about 14 times the amount of streambank-derived sediment per km of channel than from General Creek, almost 4 times more than Ward Creek, but 66% less than from the Upper Truckee River (Table 7-1). On the Upper Truckee River, channel contributions increase significantly with distance downstream from the most upstream stream gauge. These changes reflect the increasing disturbance to the Upper Truckee River in the vicinity of Washoe Meadows and downstream of the South Lake Tahoe airport as well as the decreasing influence of upland slopes. Edgewood and Logan House Creeks have been net sinks for sediment over the past 20 years. Of the streams where numerous bank-material samples were collected, relative proportions of fine-grained materials comprising the channel banks are greatest along Ward Creek and the Upper Truckee River (17% and 14%, respectively) and lowest along Edgewood and Incline Creeks.

Table 7-1. Average annual contributions of streambank materials expressed in $m^3/y/km$.

Stream	Total simulated	Total measured	Fines simulated	Fines measured
Blackwood	-	217	-	12.2
General	10.6	14.6	0.90	1.5
Upper Truckee[1]	54.5	645	9.5	90.3
Ward	45.6	-	4.4	-

[1] Rate reflects surveys over a short (2.9 km), unstable reach and, therefore are not indicative of the entire length of river.

The effect of the 1997 rain on snow event varied widely across the basin, from being a 60-year sediment event on Blackwood Creek to a 1.4-year sediment event along Third Creek. Based on magnitude-frequency analysis, western streams such as Ward, Blackwood, and General Creeks were impacted the greatest while the northeast streams were impacted the least. The January 1997 event represented only an 8-year sediment event on the Upper Truckee River near its mouth and served to flush sediment from this and other drainages. Post-1997 suspended-sediment loads are generally lower than previous because the flushing of stored sediment has made less sediment available for transport. However, in channels such as the Upper Truckee River and perhaps Trout Creek with broad, relatively flat, sinuous alluvial reaches, sediment contributions from streambank erosion have increased. This is due to extension and elongation of meanders with the ultimate development of cut-offs. Documented rates of meander migration of a reach of the Upper Truckee River have been quantified herein for the past 60 years and also show a decreasing rate of activity. It does not seem, therefore, that the runoff event rejuvenated stream channels throughout the basin. In fact, 1997 was not the peak sediment year in a number of watersheds.

Numerical simulations of suspended-sediment loadings from disturbed and undisturbed western streams, and the Upper Truckee River for the next 50 years shows a trend of decreasing sediment delivery to Lake Tahoe. This is particularly significant for the western streams because they currently produce some of the highest loadings to the lake and, over the past 20 years these high loads (per unit runoff) have remained relatively constant. That future loadings from the Upper Truckee River are simulated to decrease is significant because: (1) it is the largest contributor of suspended- and fine-grained sediment to the lake, (2) streambank erosion has increased recently, in part due to the effects of the January 1997 storm, and (3) notwithstanding the recent increase in bank erosion, loads (per unit runoff) over the longer term (past 24 years) have been shown to be decreasing. Results of simulations on the Upper Truckee River indicate that this longer-termed trend will continue and that the effects of 1997 event will be short-lived in the modeled watersheds. The accuracy and reliability of the numerical simulations is somewhat less than expected, however, because of a lack of detailed, high-quality climate data that could account for broad variations in precipitation and temperature between watersheds, and within a single watershed with elevation.

Rapid geomorphic assessments (RGAs) at 300 stream sites and stream walks were used to calculate a semi-quantitative stability index based on diagnostic characteristics of the channel and adjacent side slopes. Greater values indicate a greater potential for erosion and sediment delivery. Values greater than 19 indicate an erosion problem that can be identified from individual basin maps for the seven intensely studied streams and on basinwide maps for all other sites. Values less than 11 indicate a relative stability of channel and little to no side slope contribution. Basinwide maps of the occurrence of bank erosion and the silt/clay content of those banks can be used to evaluate potentially critical stream reaches or specific locations. Streambank-erosion classes, taking into account the proportion of fine-grained sediment in the banks were assigned to almost 50 km of channels including Blackwood, Edgewood, General, Incline, Logan House and Ward Creeks, and the Upper Truckee River.

A similar analysis of the potential for upland contributions is based on GIS analysis of five parameters including slope steepness, surficial geology, precipitation, land use/landcover, and soil erodibility. The relative percentage of high upland-erosion potential within a drainage basin was positively correlated with median, annual suspended-sediment yields and can also be used to evaluate potentially critical areas.

In conclusion, the most significant findings of this research are that:

- Streambank erosion is an important contributor of suspended-sediment from disturbed streams,
- The Upper Truckee River is the greatest contributor of suspended-sediment and fine-grained sediment in the Lake Tahoe Basin,
- Sediment delivery from the Upper Truckee River could be significantly reduced by controlling streambank erosion in the reaches adjacent to the golf course and downstream from the airport,
- Blackwood Creek is a major contributor of both total and fine-grained sediment, particularly for the size of its drainage area and loads from disturbed western streams remain high.
- Loads from western streams are not increasing with time as reported by others,
- Median, long term suspended-sediment yields (per unit runoff) from northern streams are high, about the same as the wetter western streams but yields have shown significant decreases from the major development period in the 1960s and 1970s.
- Third Creek still produces a great deal of sediment for its size as a result of both upland and channel contributions.
- Disturbed watersheds contribute considerably more suspended sediment than their stable counterparts in each basin quadrant.
- Eastern streams produce the lowest sediment loads and those studied are net sinks for sediment.

- The major runoff event of January 1997 impacted western streams and the Upper Truckee River most severely, but did not seem to rejuvenate these fluvial systems. Effects were minor in the northern streams,
- The most significant effect of the January 1997 was to flush stored sediment from alluvial valleys resulting in generally lower transport rates in the years following the event,
- Numerical simulations of General and Ward Creeks and the Upper Truckee River show that suspended-sediment loads will continue to decrease from these streams over the next 50 years.

7.2 Future Research Needs

In light of the summary of results provided above and the knowledge gained during the course of this investigation, a number of research priorities have been identified. These include but are certainly not limited to:

- Determining the critical conditions for streambank failure and, therefore, streambank restoration based on a quantitative analysis of *in situ* conditions and the effects of bank-toe erosion, pore-water pressure, and the mechanical and hydrologic effects of riparian vegetation.
- A detailed, quantitative field study of Third Creek given its unusually high sediment yields (in comparison to Incline Creek) given its location and size.
- Perform detailed case-study analyses of some of the critical upland- and channel-erosion areas highlighted in this research as a means of designing appropriate erosion-control measures throughout the basin.
- Using geomorphic techniques, determine sediment-transport trends over the last 150 years to determine if trends over the past 40 years and current lake conditions represent the attenuation of conditions caused by the massive logging operations that took place in the mid- to late 1800s.
- Additional numerical simulations of upland and channel processes with improved climate data will further elucidate sediment source areas and management strategies.